REMARKS

With this amendment, Applicants have amended claims 1, 3, 22-25, 28, 31, 32, 40, 51, 53, and 54 for clarity and cancelled claims 2 and 42-43 without prejudice. Claim 1 has been amended to state that the measuring step collapses the quantum state of the ancillary qubit to a classical $|0\rangle$ or $|1\rangle$, and that this classical result, $|0\rangle$ or $|1\rangle$, indicates whether the single-qubit gate has been applied to said data qubit. Support for this amendment to claim 1 is found, for example, at least on page 18, lines 22-28, of the specification. Applicants have amended the specification in a number of places to correct typographical errors. Upon entry of the present amendment, the pending claims will be 1, 3-41, and 44-54. No new matter has been added by way of these amendments to the claims or specification.

This amendment responds to the February 4, 2005 Office Action. In the Office Action the Examiner:

- rejected claims 1-5, 14, 22-31, and 49 under 35 U.S.C. § 102(b) as being anticipated by Bennett *et al.*, 1993, *Physical Review Letters* 70, pp. 1895-1899 (hereinafter "Bennett");
- rejected claims 7 and 15-17 under 35 U.S.C. § 103(a) as being unpatentable over Bennett;
- rejected claims 8-12, 18-21, 32-34, 42, and 44-48 under 35 U.S.C. § 103(a) as being unpatentable over Bennett in view of Blatter *et al.*, 2001, *Physical Review B* 63, 174511 (hereinafter "Blatter");[1]
- rejected claim 13 under 35 U.S.C. § 103(a) as being unpatentable over Bennett in view of Blatter and in further view of Shnirman *et al.*, 1998, *Physical Review B* 57, pp. 15400-15407 (hereinafter "Shnirman"); and
- rejected claims 6, 13, 14, 18, 19, 20, and 22-54 under 35 U.S.C. § 112 as being indefinite for failing to particularly point out and distinctly claim the subject matter.

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[1] The February 4, 2005 Office Action did not provide reference information for Blatter. However, Applicants believe the Blatter reference cited in this response is the reference relied upon for the claim rejections because no other reference the Applicants have found with Blatter as the lead author appear to have the material that the Examiner relies upon in the Office Action.

THE 35 U.S.C. § 102(b) REJECTION OF CLAIMS 1-5, 14, 22-31, AND 49 SHOULD BE WITHDRAWN

The Examiner has rejected claims 1-5, 14, 22-31, and 49 as being anticipated by Bennett. With respect to claim 2, the rejection is moot because Applicants have cancelled the claim.

Claims 1, 3-5, 14. The Examiner asserts that claims 1-5 are anticipated by the teleportation process described in Bennett. In response, Applicants have amended claim 1 to clarify the differences between the claimed invention and Bennett. Bennett teaches the teleportation of a quantum state whereas rejected claim 1, as amended, recites the application of a quantum gate on the state of a data qubit.

Page 1895 of Bennett discloses a method of transferring a quantum state $|\phi\rangle$ from a data qubit (Alice) to an ancillary qubit. In Bennett, the data qubit first interacts with an ancillary qubit having known state $|a_0\rangle$. As a result of the interaction between the data qubit and the ancillary qubit, the data qubit is left in a standard state $|\phi_o\rangle$ and the ancillary qubit is left in an unknown state $|a\rangle$. At this stage of the Bennett method, the ancillary qubit contains complete information about the original state $|\phi\rangle$ of the data qubit. Then, by reversing the interaction that was applied to the ancillary qubit, the ancillary qubit is left with the original quantum state of the data qubit $|\phi\rangle$. In this way Bennett transfers the exact original quantum state $|\phi\rangle$ of the data qubit to the ancillary qubit. In contrast to page 1895 of Bennett, the coupling step in Applicants' claim 1 does not transfer the initial quantum state $|\phi\rangle$ from the data qubit to the ancillary qubit. Rather, an attempt is made to apply a single-qubit quantum gate on the state of the data qubit. In further contrast to Bennett, the measuring step in Applicants' claim 1 does not reverse the coupling action between the original data qubit and the ancillary qubit. In Bennett, the coupling interaction between the original data qubit and the ancillary qubit is reversed in order to cause the ancillary qubit to adopt the original quantum state $|\phi\rangle$ of the data qubit. In contrast, in Applicants' measuring step, the ancillary qubit is measured thereby collapsing the quantum state of the ancillary qubit to a classical $|0\rangle$ or $|1\rangle$.

Bennett, beginning on page 1896, describes a method of teleporting a quantum state. Among other differences between this teleportation process and Applicants' claim 1 is that the Bennett, page 1896, process requires the preparation of two spin-½ particles in an EPR single state. Moreover, the Bennett, page 1896, process does not measure the state of an ancillary qubit, thereby collapsing the quantum state of the ancillary qubit to a classical $|0\rangle$ or $|1\rangle$ such that the classical result, $|0\rangle$ or $|1\rangle$, indicates whether a single-qubit gate has been applied to the state of a data qubit as recited in Applicants' amended claim 1. Claims 3-5 and 14 are patentable over Bennett because they depend from claim 1.

Claim 5 is patentable over Bennett for the additional reason that Bennett does not disclose preparing a single ancillary qubit in an initial state having the form:

$$|I\rangle = \frac{a|0\rangle + b|1\rangle}{\sqrt{2}},$$

where $|0\rangle$ and $|1\rangle$ are respectively the first and second basis states for the ancillary qubit, a and b are respectively first and second probability amplitudes, and the magnitude of a and b are about the same as set forth in Applicants' claim 5. Equation (1) of Bennett does describe how two spin-½ particles are prepared in an EPR pair state. However, this does not anticipate Applicants' predetermined initial state, in which a single ancillary qubit adopts the $|0\rangle$ and $|1\rangle$ basis states with about the same probability. Equation (3) of Bennett also provides a mathematical description of the quantum state to be teleported, but does not teach anything about the value of the coefficients a and b.

Claims 22-31 and 49. The Examiner asserts that Bennett anticipates claim 22. In response, Applicants have amended claim 22 to clarify how Applicants' invention is patentably distinct over Bennett. In Applicants' claim 22, the goal is not to transfer the state of the data qubit to the second ancillary qubit as in Bennett. Rather, the goal is to apply a single-qubit gate to an arbitrary quantum state. Initially this arbitrary quantum state is on a data qubit. Once the single-qubit gate has been applied to the arbitrary quantum state, the quantum state can be moved to any desired qubit, such as back to the original data qubit.

In Applicants' claim 22, two ancillary qubits are entangled. Then a weak measurement of the data qubit and a first qubit of the two ancillary qubits (first ancillary qubit) is performed. The result of the weak measurement is used to determine whether

the single-qubit gate has been applied to the arbitrary quantum state, which, after weak measurement of the data qubit and the first ancillary qubit, resides on the second ancillary qubit.

Bennett, pages 1896-1897, describe a teleportation process in which a data qubit is coupled to a first ancillary qubit in an EPR pair through a measurement on the data qubit and the first ancillary qubit. Raynal *et al.*, *Criteria for the Implementation of Projective Measurements in Quantum Optics,* In Proceedings of the Seventh International Conference on Quantum Communication, Measurement and Computing QCMC 2004, held July 25-29, 2004, in Glasgow, UK, pages 91-95, American Institute of Physics, New York, 2004 (Reference CA in the enclosed Information Disclosure Statement) notes that the Bennett measurement is a projective measurement. See second paragraph in the introduction section of Raynal. As noted on p. 87 of Nielson and Chuang, *Quantum Computation and Quantum Information*, Section 2.2.5, (Reference CB in the enclosed Information Disclosure Statement), the possible outcomes of the projective measurement correspond to the eigenvalues *m*, of the observable.

Projective measurements and weak measurements are not the same. In a weak measurement, the possible outcomes of the measurement are not the eigenvalues *m*, of the observable. This point is noted in the first sentence of Audretsch *et al.*, "Quantum optical weak measurements can visualize photon dynamics in real time," arXiv:quant-ph/0012060 v2 December 10, 2001 (Reference CC in the enclosed Information Disclosure Statement). Furthermore, unlike projective measurements, weak measurements do not collapse the wave function of the quantum system being measured. See, for example, page 27, lines 30-33, of the specification, which states:

> A weak measurement only partially collapses the state of the measured qubit and hence only provides a probabilistic result. The use of a weak measurement in circuit 401 advantageously allows for the preservation of the quantum state to which a single-qubit gate is to be applied.

The specification continues with more details of such weak measurements (See at least page 27, line 33, through page 28, line 14, of the specification).

In addition to the patentably distinct type of measurement recited in claim 22, claim 22, as amended, is also patentable over Bennett because Bennett does not disclose the determining step of claim 22. In contrast to the projective measurements of Bennett,

where the state of the second ancillary qubit at the end of measurement is always known, the weak measurement of Applicants' claim 22 provides only a probability of success. Thus, Applicants must use the results of the measuring step to determine whether the single-qubit gate has been applied to the arbitrary quantum state that was initially on the data qubit. In fact, a series of weak measurements may be required to successfully apply the single-qubit gate to the arbitrary quantum state. This series of weak measurements are described at least in dependent claims 23-31 as well as Fig. 4A of the specification and the accompanying text. Claims 23-31 and 49 are patentable over Bennett because they depend from claim 22.

Claims 26-31 are patentable over Bennett for the additional reason that Bennett does not disclose correcting for a Hermitian conjugate. The standard for anticipation under 35 U.S.C. § 102 is strict identity. Anticipation under 35 U.S.C. §102 can only be established by a prior art reference that teaches each and every element of the claimed invention. *Structural Rubber Products Co. v. Park Rubber Co.* 223 USPQ 1264 (1984). In the February 24, 2005 Office Action, claims 26-31 were rejected under 35 U.S.C. §102(b) because "it is understood that the corrections will be applied as necessary." Applicants note that Bennett does not discuss any such correction, much less a correction for correcting the application of the Hermitian conjugate of the single-qubit gate so that the actual single-qubit gate is applied to the state of an arbitrary quantum state initially on a data qubit. Nor does Bennett render claims 26-31 obvious because there is no need to apply corrective action. The stated goal of Bennett is to transfer a qubit state, not apply a single-qubit gate. So there is no motivation in Bennett to apply corrective action in Bennett in order to obtain the correct single-qubit gate.

As an additional matter, Bennett does not render the rejected claims obvious. To reject claims under 35 U.S.C. § 103, the patent office bears the initial burden of establishing a prima facie case of obviousness. *In re Bell*, 26 USPQ2d 1529, 1530 (Fed. Cir. 1993). When a 35 U.S.C. § 103 rejection is based upon a modification of a reference that would render the prior art invention being modified unsatisfactory for its intended purpose, than there is no suggestion or motivation to make the proposed modification. *In re Gordon* 221 USPQ 1125 (Fed Cir 1984); and Section 2143.01 of the Manual of Patent Examining Procedure, Original Eighth Edition August 2002, (February 2003 Revision), page 2100-127, first paragraph of the Section entitled "The Proposed Modification Cannot Render the Prior Art Unsatisfactory for its Intended Purpose." Modifying Bennett

such that weak measurements rather than projective measurements are performed would render Bennett, as modified, unsatisfactory for its intended purpose. The intended purpose of Bennett is to transfer a quantum state. The use of a projective measurement allows for a transfer of this state to occur with absolute certainty. If Bennett were modified to use weak measurements, there would be no certainty that the quantum state had successfully transferred. Thus Bennett, as so modified, would be unsatisfactory for its intended purpose.

In light of these arguments, Applicants respectfully request that the 35 U.S.C. § 102(b) rejections of claims 1-5, 14, 22-31, and 49 be withdrawn.

THE 35 U.S.C. § 103 REJECTION OF CLAIMS 7 AND 15-17 SHOULD BE WITHDRAWN

The Examiner has rejected claims 7 and 15-17 as being obvious in light of Bennett. Claims 7 and 15-17 depend from claim 1. With this response, claim 1 has been amended so that it is patentable over Bennett. Moreover, Applicants believe that Bennett does not render claim 1 obvious. Modification of Bennett in order to render claim 1 obvious would make Bennett unsatisfactory for its intended purpose. In Bennett, the goal is to transfer a quantum state to an ancillary qubit. Yet, in claim 1, the quantum state is altered by the application of a single-qubit gate. As such, Bennett does not render claim 1 obvious. Claims 7 and 15-17 are not rendered obvious by virtue of the fact that they depend from claim 1. In light of these arguments, Applicants request that the 35 U.S.C. §103 rejection of claims 7 and 15-17 be withdrawn.

THE 35 U.S.C. § 103 REJECTION OF CLAIMS 8-12, 18-21, 32-34, 42, AND 44-48 SHOULD BE WITHDRAWN

The Examiner has rejected claims 8-12, 18-21, 32-34, 42, and 44-48 as being unpatentable over Bennett in view of Blatter. With respect to claim 42, the rejection is moot because the claim has been cancelled without prejudice.

Claims 8-12 and 18-21 ultimately depend from claim 1. As noted in the response to the 35 U.S.C. § 103 rejection of claims 7 and 15-17 above, Bennett does not render claim 1 or any claim that depends on claim 1 obvious. Blatter does not remedy the

deficiency in Bennett. Blatter merely describes specific types of superconducting-phase qubits.

Claims 32-34 and 44-48 ultimately depend from claim 22. As noted in the response to the 35 U.S.C. § 102(b) rejection of claims 1-5, 14, 22-31 and 49, above, Bennett does not render claim 22 or any claim that depends on claim 22 obvious. Blatter does not remedy the deficiency in Bennett. Blatter merely describes specific types of superconducting-phase qubits. The combination of Bennett and Blatter does not render claim 47 obvious for the additional reason that neither reference teaches or suggests a permanent readout qubit as recited in Applicants' claim 47.

In view of the aforementioned reasons, Applicants request that the 35 U.S.C. § 103 rejection of claims 8-12, 18-21, 32-34, and 44-48 be withdrawn.

THE 35 U.S.C. § 103 REJECTION OF CLAIM 13 SHOULD BE WITHDRAWN

The Examiner has rejected claim 13 as being unpatentable over Bennett, in view of Blatter, and further in view of Shnirman. Claim 13 ultimately depends from claim 1. As noted in the response to the 35 U.S.C. § 103 rejection of claims 7 and 15-17 above, Bennett does not render claim 1 or any claim that depends on claim 1 obvious. Blatter merely discloses types of qubits and therefore does not remedy the deficiencies in Bennett. Shnirman merely discloses a type of SET transistor and also does not remedy the deficiencies in the combination of Bennett and Blatter. For these reasons, claim 13 is patentable over any combination of Blatter, Bennett, and Shnirman.

Claim 13 recites applying a Josephson gate between a data qubit and an ancillary qubit. The Examiner reasons that Shnirman shows that quantum measurements can be performed with interconnected SSETs and provides an alternative to the Blatter approach and the use would be obvious since superconducting weak links are not needed which would simplify fabrication. Shnirman uses a SET coupled to a superconducting charge qubit to read out the state of the qubit. Shnirman does not show using a SET to couple any qubits together. Therefore claim 13 is not rendered obvious by Shnirman for the additional reason that coupling between qubits is recited in claim 13. In addition, Shnirman uses charge qubits, while Blatter uses phase qubits. It is not clear how the SET of Shnirman, which can detect charge but not phase differences, could be combined with

the phase qubits of Blatter to achieve coupling or measurement. Accordingly, Applicants request that the 35 U.S.C. § 103 rejection of claim 13 be withdrawn.

THE 35 U.S.C. § 112 REJECTION OF CLAIMS 6, 13, 14, 18, 19, 20, AND 22-54 SHOULD BE WITHDRAWN

The Examiner has rejected claims 6, 13, 14, 18, 19, 20, and 22-54 as being indefinite for failing to particularly point out and distinctly claim the subject matter.

Claims 6, 13, 14, 18, 19, and 20 have been rejected by the Examiner because the specification allegedly fails to provide sufficient information to particularly point out and distinctly claim how the gates recited in these claims (X gate, claims 6, 19; Josephson gate, claim 13; Z gate, claim 14; XX gate, claim 18; and YY gate, claim 20) are implemented. Applicants traverse the rejection on the basis that there is ample support in the specification to implement the gates in the manner claimed in claims 6, 13, 14, 18, 19, and 20.

As noted on page 2, lines 29-32, of the specification, a quantum gate is a unitary transformation performed on the Hamiltonian of a qubit. Such gates can be represented as matrices acting on the basis states of the qubits, which in turn are eigenvectors of a Pauli matrix as noted on page15, lines 17-32, of the specification. Thus, a quantum gate acting on the state of a qubit can be represented by the multiplication of a unitary matrix with an eigenvector that contains the state of the qubit. In turn, a quantum gate can also be represented by a specific term in the Hamiltonian of a qubit or qubit system as noted on page 16, lines 6-8, of the specification.

Page 14, line 19, through page 15, line 3, of the specification shows an example of a Hamiltonian for the qubit register 100. The total Hamiltonian H_S is composed of three terms, each of which represents a different type of unitary transformation that can act on the qubit. H_X represents an X gate, which is described by the Pauli X matrix (shown on page 14, line 30, of the specification), and is a single qubit gate that performs a bit flip operation (see page 14, lines 21-22, of the specification). Similarly, the Z gate (Paul Z matrix) is represented by H_Z and performs a phase flip. H_{ZZ} is two-qubit gate, and is variously called a Josephson coupling, Josephson gate, Ising coupling, and ZZ gate in both the art and the specification. The matrix representation of the ZZ gate is the tensor product of two Pauli Z matrices and as shown page 17, line 1, of the specification. Other

such Hamiltonian terms are possible, with the subscript describing the type of unitary operation performed (*e.g.* X, Y, Z, XX, YY, ZZ, and XY).

The implementation of a general two-qubit quantum gate is described on page 16, lines 9-30, of the specification. The example shown is for implementing a ZZ gate using system 100. For other types of two-qubit gates, the type of qubits used and the type of coupling device between the qubits determines which types of gates (XX, YY) can be performed as noted on page 15, lines 4-14, of the specification. The specification teaches that two-qubit gates are used to indirectly perform single qubit gates. For example, page 17, line 22, through page 18, line 21, of the specification describe performing a ZZ gate on a data qubit and an ancillary qubit to indirectly apply a Z gate on the data qubit. Thus, the implementation of single qubit gates is dependent on the implementation of two-qubit gates in the present invention.

Shown in Table 1 is a list of locations in the specification where various gates are described, either by a matrix, equation, a Hamiltonian term, or a physical implementation.

Table 1 - Support for Quantum Gates in the Specification

Gate - with alternate names and representations listed	Page	Lines
Z gate (H_Z, Pauli Z gate, phase-flip operation, σ^Z gate)	4	32-33
	5	1-5
	6	15-27
	15	24-32
	16	1-8
Y gate (H_Y, Pauli Y gate, σ^Y gate)	14	18-31
	15	24-32
X gate (H_X, Pauli X gate, bit-flip operation, σ^X gate)	14	18-31
	15	24-32
	16	1-8
	17	2-11
ZZ gate (H_{ZZ}, Josephson gate, Ising coupling, $\sigma^Z \otimes \sigma^Z$ gate)	14	18-26
	16	9-30
	17	1
	18	6-21
	26	18-31
YY gate (H_{YY}, $\sigma^Y \otimes \sigma^Y$ gate)	15	4-16
	22	25-32
XX gate (H_{XX}, $\sigma^X \otimes \sigma^X$ gate)	15	4-16
	22	25-32

Gate - with alternate names and representations listed	Page	Lines
	26	18-32
	27	1-2
	32	24-28
	33	1-6
YX gate (H_{YX}, $\sigma^Y \otimes \sigma^X$ gate)	33	7-10

In addition, page 3, lines 16-23, of the specification incorporates by reference several publications that further describe unitary quantum gates. In summary, Applicants believe that the specification provides sufficient description of how the aforementioned gates are implemented in the manner recited in claims 6, 13, 14, 18, 19, and 20 to satisfy the requirements of 35 U.S.C. § 112, second paragraph.

Claims 22-54. The Examiner has rejected claims 22-54 for allegedly failing to specify how the second ancillary qubit is created or applied. Applicants traverse the rejection. The specification teaches how to create and apply ancilla qubits. Starting at page 22, line 6 through page 23, line 16, as well as page 25, line 31, through page 26, line 9, are methods for creating ancilla qubits. The use of the second ancilla as defined in claims 22-54 is enabled by at least page 24, line 9, through page 31, line 9, of the specification. As noted on page 24, lines 11-12, the methods can be performed on any system that is described by an exchange Hamiltonian. Systems described by an exchange Hamiltonian are described at least on page 22, line 19, through page 24, line 6, of the specification, in which numerous references to exchange systems are incorporated by reference. In the methods recited by claims 22-54, the data qubit, and the first and second ancillary qubits are any qubits in a quantum system that can be described with an exchange Hamiltonian.

Claims 50 and 51. The Examiner has rejected claims 50 and 51 as allegedly being indefinite. In response, Applicants note that the different qubit types that can be used in the present invention are described at least on page 13, line 16, through page 14, line 2, of the instant application and that such types include superconducting phase qubits, (*e.g.* d-wave grain boundary qubit), superconducting charge qubits, and quasi-charge qubits, permanent readout superconducting qubits, and two junction flux qubits. All that claim 50 recites is that each of the data qubits be of the same qubit type. Conversely, all that

claim 51 recites is that the first and second ancillary qubits are not the same type of qubit as the data qubit.

Claim 53. The Examiner has rejected claim 53 because the term universal gate recited in claim 53 is not defined. Applicants have amended claim 53 to make it clear that the plurality of applications of the single qubit gate are used to create a plurality of composite gates that form a universal set of gates. As noted on page 3,. lines 13-15 of the specification, almost any two-qubit gate, when combined with single-bit gates, forms a universal set. The specification further references Barenco *et al.*, 1995, Physical Review A 52, p. 3457, and Dodd *et al.*, 2002, Physical Review A 65, 040301 [pre-print arXiv.org: quant-ph/0106064], respectively these are references AL and AQ of the Information Disclosure Statement filed with the United States Patent and Trademark Office on September 29, 2004, which provides more details on universal sets of gates. For these reasons, Applicants believe that claim 53 particularly points out and distinctly claim the subject matter that Applicants regards as their invention.

Claim 54. The Examiner has rejected this claim because the claimed process has allegedly not been described in such a way as to permit its use. Applicants respectfully point out that claim 54 is supported at least by page 27, line 11, through page 29, line 17, of the specification. Furthermore, Applicants have amended claim 54 to recite the use of a weak measurement. As noted in Applicants' response to the 35 U.S.C. § 102(b) rejection of claims 1-5, 14, 22-31, and 49 above, a weak measurement cannot guarantee application of a gate. Therefore, a determining step is need in claim 54 to see whether the weak measurement applied the desired single-qubit gate to the arbitrary quantum state. When the data qubit and the first ancillary qubit are in a singlet state, the gate was successfully applied. Conversely, when the data qubit and the first ancillary qubit are in the triplet state, the gate was not successful and a corrective operation is required.

For the forgoing reasons and in light of the claim amendments made, Applicants believe that claims 6, 13, 14, 18, 19, 20, and 22-54 are fully patentable and request that the rejection of these claims under 35 U.S.C. § 112, second paragraph, be withdrawn.

CONCLUSION

Applicants respectfully request that the above-mentioned amendments and remarks be entered and made of record in the file history of the subject application. It is believed that all claims are fully allowable and early indication of the same is earnestly sought.

It is believed that no fees are due in connection with the filing of this amendment. However, should the Unites States Patent and Trademark Office determine otherwise, please charge the required fee to Jones Day deposit account no. 50-3013, referencing CAM No. 706700-999148.

Respectfully submitted,

Date: June 6, 2005

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